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Research article

Risk Assessment Analysis of Hybrid Renewable Energy Systems in Remote Areas: Case Study of Domadgee, Australia

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Abstract: This study comprehensively analyses the energy requirements and options for Doomadgee, a remote indigenous community in Australia. Currently, the electricity provider relies on a 2.44 MW diesel power generator, resulting in high operational costs and carbon emissions. This study explores transition options to renewable energy sources to address these challenges while ensuring reliable and cost-effective power supply. This study suggests utilising a 2.4 MW wind energy source, a 1.2 MW solar energy source, and a 4 MW battery storage system that can last 8 hours. This configuration aims to reduce diesel consumption, optimise the internal rate of return (IRR), and establish a sustainable energy mix with low capital expenditure. The wind and solar capacities recommended for Doomadgee also consider seasonal fluctuations, such as wet and dry seasons in energy demand, ensuring efficient power production all year round. The study commences with the development of a risk matrix to determine the hurdle rate. The next step involves conducting ten distinct scenarios to evaluate the investment's financial feasibility, considering various variables such as wind, solar, equipment, and battery storage capacities. Sensitivity analysis also determines the most significant factors impacting financial valuation. This analysis provides valuable insights that can aid in the decision-making process.

Keywords: renewable energy, risk assessment, remote areas, Australia.

1. Introduction

Located 125km from south Gulf Carpentaria and 90km east of Queensland, Doomadgee is a place of indigenous people that can be considered quite remote. Burketown is the closest township, about 80km to the east, and Cairns is the nearest city centre, with around 760km of travel distance to the east of Doomadgee. Doomadgee has three traditional people: Waanyi, Gangalidda, and Garawa. The total population in 2020 was approximately 2000 people, and its population is projected to increase gradually over the following years [1]. Doomadgee administration and management were handed to the Queensland government in 1983, and through the Aborigines ACT 1984, the Doomadgee Aboriginal Community Council was successfully established. However, in 2010, there were structural changes within the council, and a new Doomadgee Council was established to replace the previous council. It is called the Doomadgee Aboriginal Shire Council, and a mayor and four other councillors represent it. The Doomadgee Shire Council has the responsibility to manage and develop around 1,821km2/ 116 hectares that include land uses and purposes such as an airport, rodeo, workshop, services, school/education, health, and solar farm for electricity [2].

Doomadgee is supplied with electricity by the Queensland government. Currently, the community is managing 2.44 MW of diesel power generators and has constructed a 576 kW solar farm and a 105 kW solar rooftop system. Most of its diesel operation expenses are paid for its petroleum supply. One viable strategy for mitigating substantial waste in community budgets is to increase the implementation of renewable energy sources (RES), such as solar photovoltaics [3]. Australia, in comparison to all other continents, receives the highest amount of solar radiation per square metre, creating it a globally abundant resource of renewable energy [4]. It is anticipated that the cost of photovoltaics will be more stable and affordable in the future decades than fossil fuels, which will increase the likelihood of widespread adoption of green energy [5]. Furthermore, in comparison to other states, Queensland is commonly distinguished by its comparatively high average number of sunlight hours [6]. This transformed Doomadge into an area suitable for additional solar PV installations. Figure 1 depicts the overview map of Doomadgee.

Figure 1. Domadgee map [7].

Presently, Australia's wind energy contribution stands at a considerably higher 12%, surpassing even the energy output of sizable solar farms. The substantial presence of these energy sources in the grid can be attributed to their environmentally favourable characteristics in comparison to conventional sources [8], [9], [10]. Overall, wind speed in Australia surpasses the mean value in certain regions, resulting in substantial increases in its energy share over time [11], [12]. Therefore, wind turbines would complement the hybrid power plant (HPP) system in Doomadge.

One primary drawback of exclusively relying on RES is their intermittent nature, which means they may be unavailable under specific conditions and at particular times. Sometimes, clouds may cover the area and the wind speed required to generate electricity is not enough. As a result, a hybrid system consisting of battery storage and a diesel generator may be needed to supplement the dependability of RES.

Numerous studies on the techno-economic analysis of HPPs have been undertaken in various locations. An investigation into the benefits of replacing diesel generators with HPP via RES was carried out at Uttara University. According to the assessment, renewable HPP can potentially reduce energy costs (COE AUD/kWh) by nearly 45% compared to diesel generation [13]. Diesel generators with RES, RES alone, and RES with hydrogen (H_2) storage are just a few examples of the various energy source components that have been combined in nearly every HPP study [14], [15], [16], [17]. This study tries to explore HPP options. Aside from reducing emissions, its other objective is to reduce the operating costs of diesel, and it is planned that diesel should only be used for emergencies. 4,5 MW of solar farm is currently being proposed by the Queensland government to fulfil the energy demand of Doomadgee on an average of 8,3 GW in both wet and dry seasons.

An assessment of HPP efficacy under distinct climatic conditions was conducted in 2023, specifically focusing on a region in India. The investigation encompassed a range of climatic conditions, including cold, dry, composite, temperate, and warm conditions. It reveals that the HPP may perform differently under various climatic conditions; for example, wind energy is typically incompatible with colder regions. Incorporating the climatic conditions of the evaluated location is crucial for optimising the potential resources of RES. Additionally, the advantages of adapting HPP evaluation to climatic conditions may increase productivity and dependability [18]. Furthermore, a more recent study concerning off-grid (HPP) in Bahia has contributed to the assessment of HPP in terms of its benefits and drawbacks. The study concludes that off-grid HPP is impractical and incapable of meeting Bahia's energy demands due to financial constraints. However, economic, social, and environmental benefits become apparent as the proposed HPP supply is reduced to 25% of energy demand. Combining HPP generated from RES with grid connectivity will enable the project's implementation [19]. In Libya, where inadequate electricity generation hinders community supply production, it has been demonstrated that grid-connected PV can alleviate this issue. Furthermore, the study also emphasised the significance of the PV installation's location, which has both environmental and economic benefits, particularly in terms of emissions reduction [20].

This research will evaluate HPP, which is constructed using multiple renewable and non-RES. HPPs are commonly employed in remote regions where they are necessary to meet the energy needs of the local community. Having HPP necessitates the generation capacity to be carefully sized to achieve optimal energy costs and prevent capacity oversizing, which frequently results in energy loss. Additionally, this research will evaluate the investment analysis, delving into various combinations of scenarios that will ultimately result in the highest possible return. Therefore, this techno-economic analysis study will comprehensively examine the proposed HPP, including risk assessment of project elements, financial evaluation, and electrical system components.

The Risk assessment will use environmental, social and governance (ESG) as an approach to analyse the potential risks and solutions. The study's financial investment flow will use multiple assumptions based on actual data, which will be further discussed in the following paper sub-sections. The study will provide various scenarios to compare the best alternative options that could be invested in this study. Moreover, an illustration of the energy flow diagram will support the study's conclusion and recommendations that show the proportion of installed capacity from various power generation, either renewable or non-renewable. Ultimately, the study will provide recommendations based on IRR and Hurdle rate that can be considered as sources of financial investment decision (FID).

2. Methods

2.1. Risk Assessment

It is important to have an eye on potential risks that may bring harm to the project, which includes the project being halted, stopped and shut down before the expected contract runs out. Installing the project in a remote indigenous land requires a holistic and transparent view of the risks that involve ESG. In grouping down the ESG approach, the risk assessment will have six different groupings, ranging from political, environmental, social, technology, law and economy. Each risk will be assessed based on its risk consequence (*s*), likelihood (*l*), and impact on society, environment and economy (*i*). Risk consequence shows how long the risks will be affected, and risk likelihood elucidates the level of probability of a risk, while the impact on society, environment and economy will show how strong it will be impacting these sectors. In assessing the risks, a scale of 1-5 will be used to determine the weight of the risks, with five being the highest. Risk consequences, likelihood, and impact on society, the environment, and the economy will have a maximum weight of 40, 40, and 20, respectively. Equation (1) depicts the formula for determining project risks

$$\text{Risk assessment score} = \left. \frac{Sc\ x\ Mc + Sl\ x\ Ml + Si\ x\ Mi}{Mc + Ml + Mi} \right/ 5x100 \qquad (1)$$

where (*s*) represents the amount scale while (*M*) represents the maximum number in the residual risk.

Each potential risk will be scored in raw and residual risks, and a formula is used. Raw risks illustrate the proportion of the risks before evaluation, while residual risks score will represent how much the proportion of the score declined after mitigation/ evaluation is taken. Ultimately, the study will show the risk assessment result graph. The graph will illustrate which risks are considered highly important. Crucial risks that should be prioritized to be mitigated and evaluated will also be shown within the graph to provide a clear future path of risk mitigation.

2.2. Potential Risks

There are 30 risks found that could happen before, during and after the project runs. The study will highlight top priority risks from each grouping that can be seen in the result of the risk assessment graph. Those risks are highly important and should be mitigated early because of their cruciality, which may negatively impact the project. Social, environmental and technical risks dominate the overall result score, followed by economic, political, and legal.

2.2.1. Environmental Risk

Doomadgee is prone to bushfires. Construction of the project will require area clearing which involves heavy vehicles. Frequently, vehicles are the source of weed spread in Australia's remote places due to high mobility. Weed is the fuel of bushfires, and it could quickly burn even without fire and can potentially occur during the dry season. Installation of mobile washdown facilities by the company would be a great way to remove any weeds attached to vehicles. Table 1 shows the environmental risk matrix score.

Table 1. Environmental risk matrix score.

Risk category	Sum of the raw risk score	Sum of the residual risk score
Spread of Weeds	96	40
Biodiversity disruption	80	64
Changing climate patterns	76	36
Visual impact	72	40
Landspaces Changes	68	32

2.2.2. Social Risk

Constructing the facilities will require engineers from outside of Doomadgee. The construction process will take approximately 2-5 months, and the workers will stay and blend with the locals. There might be some potential where habits from workers who live in urban such as playing music out loud after working hours. Hence, this will be the most significant risk in a social grouping where conflict may occur. Adjusting the worker's SOP would effectively reduce the risks and maintain a positive attitude with the locals. Moreover, the Aboriginal and Torres Strait Islander Act in 1991 has shown ownership of the Doomadgee people's land, meaning permission for project construction to Doomadgee Shire Council is strongly advised to avoid occupying the protected land of Doomadgee. To reduce these risks, the electricity provider is required to consult with the state government to approach the Doomadgee Shire Council and get permission. If such risks are not mitigated, the project will not run. Table 2 shows the social risk matrix score.

Table 2. Social risk matrix score.

Risk category	Sum of the raw risk score	Sum of the residual risk score
Residences and local housing may be demolished	84	60
Losing social license to operate	84	40
Worker health, safety, and wellbeing	84	36
Demand for qualified workers/technicians not met	56	28
Waste of energy	72	32
Lack of public awareness	88	48
Worker-related to diesel may be jobless	80	48
Worker conflict with the locals	88	48

2.2.3. Technical Risk

During asset operation, serious technical issues can potentially happen. These issues often require the company’s experienced engineer to fix them directly. The closest major city that may provide senior engineers for renewable technology is Cairns, where travelling through airplanes and road vehicles requires 3 and 12 hours, respectively. Moreover, flights are not usually available every day. Hence, online video calls through various platforms will be the best alternative for locally trained maintenance staff. Technical risk matrix score is shown in Table 3.

Table 3. Technical risk matrix score.

Risk category	Sum of the raw risk score	Sum of the residual risk score
Asset may be damaged due to high heat stress	76	60
Arc flash to a switchboard	72	60
Interconnection in grid connection	68	40
Malfunction - blackouts	84	48
More time is needed for sudden serious technical issues	100	60
Material transport	80	52
Leakage	60	36

2.3. Hurdle Rate

The hurdle rate is important in assessing a project's viability and feasibility. It serves as a crucial benchmark for determining whether or not the project should be continued. In this case, the hurdle rate is calculated by multiplying the weighted average cost of capital (WACC) with the risk assessment previously conducted. According to the analysis, the primary sources of risk are environmental, social, and technical factors. A ratio of 2.0 will be applied to multiply WACC. According to the investment financial analysis, the project can be implemented as the IRR value is higher than the total hurdle rate of 5.2%.

2.4. Financial Assessment

Technology invested is crucial to be assessed through the financial flow to find the best-recommended option. The energy investment assessment in this study is meant to find the least Capex with the highest possible IRR and highest saving of litre in diesel fuels. The conducted financial assessment is shown for 40 years ahead based on the project's brief note (MSE, 2023).

The financial assessment is started by calculating the amount of capital expenditure spent for building solar/ wind facilities that come with fixed costs such as construction and working labour. Second, the avoided diesel costs will be put into the revenue, and renewable electricity generation will not be considered revenue because electricity prices are ignored due to government-funded projects. Then, the revenue will be subtracted from operational expenditure, which will be called EBITDA. Each technology will be depreciated until 0 each year, depending on the assets' lifetime; in this case, solar and wind have 20 years of lifetime, while the battery has only 10 years of life. Hence, solar and wind assets will be depreciated by 5% each year in 20 years and 10% for batteries in 10 years. The EBIT is necessary to find the net profit after tax (NPAT), and the EBIT value is calculated by subtracting the depreciation rate from EBITDA. It continued by seeing the amount of NPAT, which resulted from the deduction of EBIT to TAX, which weighed 30%. The free and discounted cash flows are calculated using the formula below.

Financial cash flow is an important value that measures the ability of financial stability through the amount of cash from the company's invested project. FCF is calculated from EBIT multiplied by the amount of EBIT after taxes plus the depreciation rate that CAPEX subtracts. Then, it is followed by the FCF divided by 1+tax rate to the power of a number of year period. Finally, the IRR would come from the SUM of DFCF, usually called Net Present Value (NPV), which is transformed into zero value.

An assumption needs to be made within this study that considers the working labour and technology price. It is worth noting that working labour will always increase through time. Hence, a percentage of increases is expected to happen in solar, wind and battery. On the other hand, technology prices will go down as innovation and efficiency increase, and more supply will become more viable. The assumption is taken from the average increase and decrease projected by CSIRO (Graham et al., 2023).

3. Results and Discussion

3.1. Data and Assumptions Used

The financial assessment uses multiple data variables from different sources, such as official documents from the Australian Government website. The economic assumption is mainly based on the memorandum. Multiple variables of solar, wind and battery installation measured in AUD/kW are provided, and the study takes the average between low and high scenarios from the memorandum. The weighted average cost of capital/ discount rate is also shown within the document, accounting for 2,6%. Table 4 illustrates the primary data used.

The labour and technology costs analysed over forty years along with the price assumptions for each technology. Given the project's forty-year duration, it is imperative to incorporate information regarding the annual 3.7% change in work wages, as reported by the Australian Bureau of Statistics [21]. Therefore, if solar and wind assets are replaced every 20 years, the working wage of fixed costs will increase by 66% over the same period; the same holds for batteries.

The capacity of the existing diesel technology is 0.681 MW. The main objective of this device is to ascertain the amount of diesel fuel that is not being utilised. It is noteworthy that the investment calculation will not incorporate this diesel capacity. The annual production capacity of the diesel system at its present level is 1,225 MWh. Consequently, the forthcoming situation will lead to a decrease in diesel energy generation by 7,055 MWh annually. The calculation is being performed in scenario 0, also called the baseline scenario.

It has been noted that Doomadge experiences two discernible seasons, exclusively arid and wet, corresponding to different energy requirements. Consequently, it is critical to account for the energy production calculation during each respective season. Analysing the total energy production from wind and solar sources makes it possible to identify the technology that will necessitate the most capacity. The aforementioned data is subsequently employed to generate suggestions.

Table 4. Annual wind and solar energy production per 1 kW capacity.

Season	Wind (MWh)	Solar (MWh)
Wet	662	539
Dry	1,296	808
Additional Wet	487	454
Total	**2,445**	**1,801**

Based on the data in Table 4, wind energy generation exceeds solar energy generation by a margin of 2,445 MWh per kilowatt-hour capacity. The data suggests that wind performance is consistent throughout the day and night, although comparatively weaker during the rainy season than during the dry season. Based on the analysis, Solar's production limitations render it susceptible to failing to meet demand. Solar photovoltaics (PV) exclusively produce energy during daylight hours, averaging 8-12 hours of production time. Based on the information, the annual total demand that necessitates fulfilment is 8,280 MWh.

3.2. Scenarios

Four solar and wind energy scenarios were investigated for the study, each involving batteries of differing capacities. The analysis identifies four distinct configurations of the utilised battery storage: 6 MW for four hours, 6 MW for eight hours, 4 MW for four hours, and 4 MW for eight hours. According to the GENCOST document, a price differential can be hypothesised among batteries of varying durations [22]. To illustrate, a four-hour battery might be around 15% less expensive than one lasting eight hours. It is apparent from Table 5 that wind energy exhibits a comparatively reduced average CAPEX cost in relation to solar PV. The analysis indicates that the IRR produced by all wind scenarios exceeds 10%, whereas the IRR produced by solar PV falls well below 8%.

Table 5. Wind and solar scenarios.

WIND SCENARIO					
Capacity (MW)	**Total Capex (AUD)***	**Diesel Savings (L)**	**Diesel Consumption (L)**	**Battery**	**IRR (%)**
3	29,852,036	1,913,056	1,327,457	6MW 8HRS	13.32
3	26,201,772	1,885,502	1,355,011	4MW 8HRS	14.59
3	31,784,528	1,916,441	1,324,072	6MW 4HRS	12.47
3	27,490,100	1,892,708	1,347,805	4MW 4HRS	14.05
SOLAR SCENARIO					
Capacity (MW)	**Total Capex (AUD)***	**Diesel Savings (L)**	**Diesel Consumption (L)**	**Battery**	**IRR (%)**
4,5	32,598,517	1,769,866	1,470,647	6MW 8HRS	7.33
4,5	28,948,254	1,608,386	1,632,127	4MW 8HRS	4.46
4,5	34,531,010	1,777,873	1,462,640	6MW 4HRS	6.94
4,5	30,236,582	1,612,822	1,627,691	4MW 4HRS	4.20

*1 AUD = 0.65 USD

The high proportion of IRR acquired by wind is influenced by the total cost of diesel avoided in each scenario. It is possible to conclude that wind energy yields a more significant average revenue than solar energy, presuming diesel fuel costs AUD 1.8 per litre. As a consequence of the relatively modest capacity and variety of batteries utilised, the investment value is diminished, according to the study.

The energy flow diagram is presented in Figure 2. The EFD displayed is the optimal outcome obtained from five Enercon E40 600 kW wind turbines operating independently. The study highlights that energy spillage occurs in all scenarios, even in the optimal scenario, without integrating solar energy. The spillage is a result of the hourly mechanism of supply and demand. When the supply surpasses the demand, and the battery is fully charged, any surplus energy will go to waste.

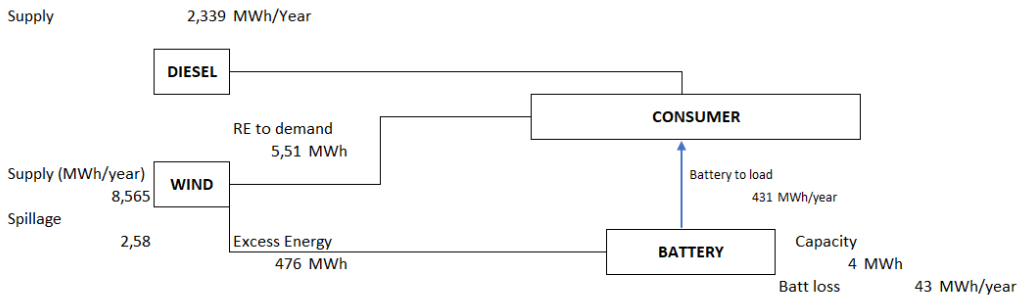

Figure 2. Energy flow diagram of diesel-wind-battery.

3.3. Recommended Combination

Based on the scenarios, it is advisable to incorporate a blend of solar and wind energy sources to maximise the return on investment (IRR) and minimise diesel expenses. The maximum annual energy production capacity of the implemented combination is 8,096 MWh, supplied by a 4.5 MW solar capacity. Incorporating these technologies is crucial for minimising potential hazards in Doomadgee, specifically those related to the environment. The combination scenario employs a 4MW battery for an 8-hour following the previously collected scenario data. The battery efficiency increased to 4MW for eight hours from 6MW for the same duration, as indicated by the data, due to the reduced investment value. Employing a hybrid system comprising solar and wind energy sources is advisable to maximise diesel cost savings and internal rate of return (IRR), as indicated by past compelling scenarios.

3.3.1. 3 MW Wind & 0.42 MW Solar

Based on previous scenarios, combining wind and solar is recommended to optimise diesel cost savings and internal rate of return (IRR). The combination implemented has a maximum energy production limit of 8,096 MWh/year, which is generated from a solar capacity of 4.5 MW. The integration of technologies holds significant importance in mitigating potential risks, particularly environmental hazards in Doomadgee. Figure 3 shows the energy flow diagram of this combination.

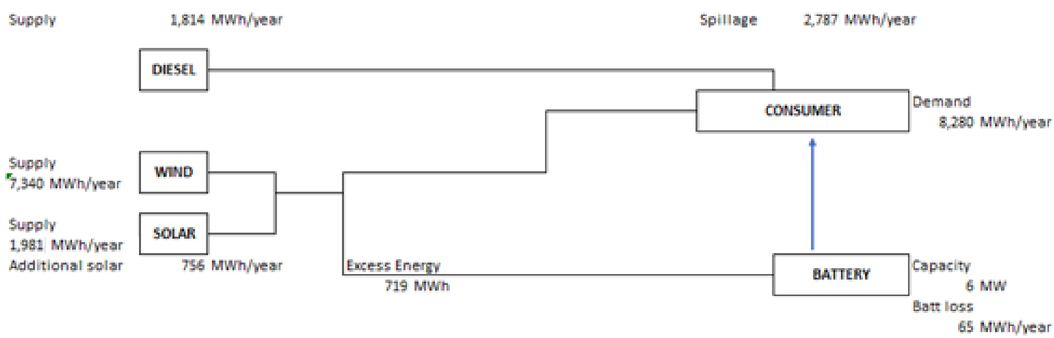

Figure 3. Energy flow diagram of 3 MW wind & 0.42 MW solar.

The first combination scenario carried out in this study is by adding 3MW/ 5 wind turbines and 0.42 MW of solar PV. This combination is based on the highest IRR in the previous wind scenario with a minimum investment value. This scenario has an IRR of 14.96% with a Capex value of $29,012,972 and can avoid the volume of diesel used as much as 1,986,496 L. Even though it has a high IRR, this scenario must have a comparison to get certainty about the best energy combination figures.

3.3.2. 2.4 MW Wind & 1.2 MW Solar

In the second scenario, four wind turbines were utilised, with a combined capacity of 2.4MW. A solar capacity of 1.2MW has been added to the scenario to meet the required supply. According to the provided information, the investment amount allocated for wind is $12,306,135, whereas the investment amount for solar is $5,675,433. Therefore, the combined scenario of the two investments has a total investment of $29,798,171. Figure 4 shows the energy flow diagram for this scenario.

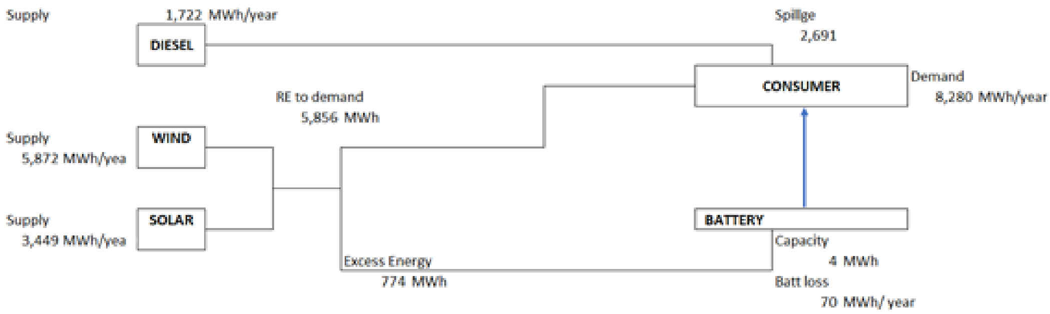

Figure 4. Energy flow diagram of 2.4 MW wind & 1.2 MW solar.

Based on the analysis, the second combination scenario yields an internal rate of return (IRR) of 15.48%. The study indicates a discrepancy of 0.52% in the IRR with the previous combined scenario. The total volume cost of unused diesel has been determined to be 2,044,168 L, the highest among all the recorded figures. According to the findings of this study, it can be concluded that the best combination is 2.4 MW of wind power and 1.2 MW of solar energy.

The combination scenario underwent a sensitivity analysis. This study outlines the variables considered in the study: the total investment value/capex of each asset, the price of diesel fuel, and the total operating costs. The study highlights the sensitivity of these variables and their impact on the overall results. This third variable was selected based on the market's fluctuating prices for each variable. According to the sensitivity analysis, withdrawing 10% of the capex can result in a 1.94% difference, leading to an achieved IRR of 17.42%. According to the study, if diesel prices increase by 10%, the initial internal rate of return (IRR) of 1.83% will decrease to 13.65%. The study incorporates the emissions that were avoided because of the recommended scenarios. According to the data provided by Natural Resources of Canada, it has been found that the emission level generated by 1 L of diesel is 2.7 $kgCO_2$. According to the data provided, installing 2.4 MW of wind and 1.2 MW of solar power can prevent a total of 5,500 tonne/year of emissions.

Based on the estimation, it has been determined that a land area of 7,040 m^2 will be required for this recommendation scenario. According to the data collected from wind power, it has been determined that an area of 1,260 m^2 is necessary to install a single wind turbine. According to the available information, it has been determined that an area of approximately 2,000 m^2 is required to generate 1 MW of power using solar PV. Hence, it is recommended that the facility be installed at the designated location outlined in the Doomadgee master plan, which consists of 6 plots of land measuring 4,000 square meters each.

4. Conclusions

In summary, this study conducted an exhaustive techno-economic evaluation to identify the most optimal hybrid renewable energy system for the isolated locality of Doomadgee, Australia. Through comprehensive financial modelling, risk assessment, and examination of meteorological data and energy capacities, it is advisable to install a hybrid system comprising 1.2 MW solar PV and 2.4 MW wind power generated by four turbines. Comparatively to the existing diesel-based system, this configuration avoids more than 2 million litres of annual diesel consumption and 5,500 tonnes of annual CO_2 emissions, resulting in the maximum internal rate of return at 15.48%. This hybrid wind-solar system featuring an 8-hour battery storage capacity of 4 MW and a total capital investment of $29.8 million offers Doomadgee a sustainable, dependable, and cost-effective energy solution adapted to the locale's environmental conditions. Seasonal fluctuations are incorporated into the analysis, land utilisation is optimised, and potential environmental, social, and technical hazards are mitigated. This transition to RES enables Doomadgee to achieve its objectives of decreasing emissions, operating expenses, and dependence on diesel, all while safeguarding the indigenous community's long-term energy security.

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